AD-A031 176 AEROSPACE CORP EL SEGUNDO CALIF ENGINEERING SCIENCE --ETC F/G 20/5
THE USE OF HOLOGRAPHIC INTERFEROMETRY FOR NONDESTRUCTIVE TESTIN--ETC(U)
SEP 76 L GOLDSTEIN, R CANNATA F04701-75-C-0076

UNCLASSIFIED TR-0076(6516-03)-1 SAMSO-TR-76-213 NL

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REPORT SAMSO-TR-76-213

The Use of Holographic Interferometry for Nondestructive Testing of Laser Windows

Engineering Science Operations
The Aerospace Corporation
El Segundo, Calif. 90245

28 September 1976

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Prepared for
SPACE AND MISSILE SYSTEMS ORGANIZATION
AIR FORCE SYSTEMS COMMAND
Los Angeles Air Force Station
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This final report was submitted by The Aerospace Corporation, El Segundo CA 90245, under Contract F04701-75-C-0076 with the Space and Missile Systems Organization, Deputy for Space Communications Systems, P.O. Box 92960, Worldway Postal Center, Los Angeles CA 90009. It was reviewed and approved for The Aerospace Corporation by A. J. Boardman, Engineering Science Operations and V. H. Monteil, Development Operations. Capt. D. Blackburn was the project engineer.

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: 18 19 SAMSO-TR-76-213
2. GOVT ACCESSION NO.:
3. RECIPIENT'S CATALOG NUMBER: 9 Technical rept.
4. TITLE (and Subtitle): 6 The Use of Holographic Interferometry for Nondestructive Testing of Laser Windows.
5. TYPE OF REPORT & PERIOD COVERED: 14
6. PERFORMING ORG. REPORT NUMBER: TR-0076(6516-03)-1
7. AUTHOR(s): 10 Lester Goldstein [redacted] Robert Cannata
8. CONTRACT OR GRANT NUMBER(s): 15 F04701-75-C-0076
9. PERFORMING ORGANIZATION NAME AND ADDRESS: The Aerospace Corporation, El Segundo, Calif. 90245
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS:
11. CONTROLLING OFFICE NAME AND ADDRESS: Space and Missile Systems Organization, Air Force Systems Command, Los Angeles, Calif. 90009
12. REPORT DATE: 11 28 Sept[redacted]76
13. NUMBER OF PAGES: 14
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 12 14p.
15. SECURITY CLASS. (of this report): Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:
16. DISTRIBUTION STATEMENT (of this Report):

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):
18. SUPPLEMENTARY NOTES:
19. KEY WORDS (Continue on reverse side if necessary and identify by block number):

Holographic Interferometry
Laser Windows
Nondestructive Testing

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The application of real time and double exposure holographic interferometry for the testing of induced strains, and internal flaws in laser windows has been explored. Techniques for employing these procedures are discussed, and holographic interferograms of several simulated stressed states of laser windows are included. The results indicate that these methods can be valuable nondestructive tools for the examination of nonuniform stresses induced by mounting hardware, and in addition, may provide for early detection of internal flaws within the window material.

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I. INTRODUCTION

Laser windows are required to physically isolate lasers and tracking equipment from external environments. In addition, they must be capable of transmitting an undistorted wavefront. Flaws within the window material can create localized strains resulting in a degradation of its optical properties or catastrophic mechanical failures. In a similar fashion, localized stresses created by pressurization or by window mounting can induce strains and thus yield similar effects. Examination of laser windows under a variety of conditions is necessary to predetermine potential problem areas and to discover degraded areas after use.

The use of holographic interferometry to analyze strains in laser windows has been investigated. Several strain configurations have been simulated and procedures and results are presented. It should be noted that this study is designed to demonstrate how holographic interferometry can be employed to provide qualitative and relative quantitative information about the strained state of a laser window.

II. BACKGROUND

The subject of holography has been aptly treated by many authors[1-5] in both books and review articles; thus, only the pertinent related points will be discussed in this report.

A hologram is formed by dividing a coherent light beam, by the use of a beam splitter, into an object beam and a reference beam. The object beam is transmitted through or reflected off the object into the hologram plane where it interferes with the reference beam, creating a standing wave pattern. The record of this pattern (usually on photographic film) is referred to as a hologram. Illuminating the processed hologram with the reference beam results in a three dimensional reconstructed image of the object appearing in exactly the same position as the original object.

Real time and double exposure holographic interferometry[6-8] have been utilized in this study. Both of these techniques are nondestructive. Real time interferograms are produced by recording an unperturbed image, viewing this image superimposed on the original object, and then perturbing the object in some manner. The fringes thus created are the result of interference between the real object, and the holographic image. The advantage that real time interferometry offers is that one can observe the effect of any perturbation as it is occurring. However, this technique requires greater stability than double exposure interferometry, and the actual fringes are much more difficult to photograph for a permanent record. Double exposure interferograms are created by recording a holographic image of both the unperturbed and the perturbed object on the same hologram. The fringes are the result of interference between two resulting holographic images. The advantage that double exposure interferometry has is that the interference pattern is permanently recorded on the hologram, and a high degree of mechanical stability is not as critical as in the real time technique. However, the pattern cannot be observed until after the interferogram is processed, and only one perturbed state (or interference pattern) may be recorded on each holographic plate.

III. EXPERIMENT

The major areas of concern which are addressed in this study include stresses induced by mounting hardware and stresses induced by pressurization of the window. In addition, the ability of this technique to detect flaws in laser windows is discussed.

Three test fixtures were fabricated and are shown in Figure 1 (a, b, c). The small pressurized cell (Figure 1a) allows an analysis of localized mounting nonuniformly induced strains. The large pressurized cell (Figure 1b) allows an analysis of flaws within the window, and the four-point loading apparatus (Figure 1c) is designed to demonstrate how relative "quantitative" information can be extracted from the data. A single set of measurements on the mounted window can provide all of the above information; however, it was not practical to fabricate this type of fixture for laboratory use.

The basic holographic set-up is depicted in Figure 2. The 514.5-nm line from a Spectra Physics Model 165 mixed-gas Krypton-Argon laser was employed throughout this investigation. Typical power levels were of the order of 400 mW with exposure times of approximately 0.05 sec. The recording media was Eastman Kodak 649F holographic film which was developed for 3 min at 70°F in D-8 diluted 2:1 with distilled water. Real time and double exposure holograms were recorded with the object beam reflected from the sample.

Holographic interferograms were obtained from the small cell (Figure 1a) by recording two exposures; one with zero pressure and one with a given pressure of between 0.5 - 5.0 lb provided from a gas bottle. Any nonuniform stress due to differential pressure of the screws, burrs in the mounting hardware, etc. will allow a nonuniform strain in the ZnSe at one edge. This strain results in a fringe pattern as shown in Figure 3. Bowing of the ZnSe is not observed on the interferogram due to the thickness to diameter ratio (1:5).

Double exposure interferograms were recorded from the large Plexiglass container (Figure 1b) by differentially changing the pressure in the water-filled cell by raising and lowering the beaker of water attached to this device. The increased pressure resulted in the interference pattern shown in Figure 4. The circular fringes are caused by the bowing of the Plexiglass. Nonuniformities from a smooth circular pattern can be interpreted as localized strain induced by defects in the Plexiglass sheet.

The final apparatus employed in this study consists of a four-point loading device. The ZnSe is placed in the position shown in Figure 1c and is stressed by applying various loads. The stress induced by this equipment has previously been established[9] and, therefore, the fringe dependence upon load could easily be correlated. The purpose of utilizing this equipment is to demonstrate the linear change of fringe pattern with a linear change of applied load. A complete series of double exposure holograms were recorded at different loads, and in all cases the linear dependence was satisfied. Figure 5 shows two typical interferograms.

IV. ANALYSIS

Holographic interference fringes are always the result of a change in optical path (that is, the index of refraction of the media which the light beam has propagated through or a change in the distance that the beam has traveled). In this study, the index of the media (air) was constant, and therefore the observed fringes were a function of displacement only. Since holography conserves all three dimensions, it is possible to study displacements (induced strains) in each direction. Qualitatively, any irregularities in a fringe or fringe pattern can be interpreted as a localized nonuniform strain. This nonuniform strain may be caused by a nonuniform stress such as from mounting as shown with the small pressure cell, or by a defect within the material, as shown with the Plexiglass cell. The detection of either case is of extreme practical importance. Quantitatively, the amount of deformation in any direction can, in principle, be determined by appropriate experiments. Unfortunately, this is sometimes difficult to realize in practice. Figure 3 provides qualitative information as to where localized mounting stresses exist, and, in fact, the pattern was easily altered by changing the tension on any screw. The sensitivity in locating defects by the bowing technique as shown in Figure 4 is difficult to evaluate from this experiment since Plexiglass rather than ZnSe was used (an appropriate size sample of ZnSe could not be obtained). Literature has indicated that defects of the order of those expected in the ZnSe can be detected by this procedure, and the present Plexiglass experiment has shown that this method can be employed on pressurized laser windows. The four-point loading technique used in this investigation was included only to indicate that a semiquantitative comparison can be realized without extensive calculations.

The geometrical sensitivity of any holographic interferometric arrangement can be determined by locating the bisector of the angle formed by the incident beam to the sample and the diffusely reflected beam from the sample (see Figure 2). The number of fringes formed by a sample displacement in direction i is proportional to this displacement times the cosine of the angle formed by the bisector and the i th direction. In the experimental set-up employed (Figure 2), the bisector is approximately perpendicular to the surface and therefore, in-plane strains have very little contribution to the fringe pattern. Strains in each direction can be investigated by adjusting the angular relationships between the light beams.

The main stress component in the pressure cell studies is perpendicular to the surface while the holographic arrangement is such that the bisector is also approximately perpendicular to the surface; therefore, this technique is very sensitive to the induced strains. Each fringe in the interferograms represents a displacement of approximately $\lambda/4$. Irregularities in the fringe pattern near the corners of Figure 4 (the straightening out of the circles) are a consequence of the edge effects caused by the sides and corners of the cell restricting the deformation. The fact that the photograph is only of the central portion of the cell indicates the long range significance of the edges.

V. CONCLUSIONS

Holographic interferometry can be extremely useful for the nondestructive testing of laser windows. The experiments reported in this study demonstrate that qualitative and semiquantitative interpretations of localized strains due to mounting nonuniformities can be obtained. A technique of bowing the sample and carefully examining the resulting fringe patterns has been presented for the detection of flaws, although the absolute sensitivity of this method for this application must await further measurements on more appropriate samples and/or a detailed extensive series of mathematical and structural calculations (see, for example, Reference 10). Holographic interferometry can easily be employed with laser windows and is inherently capable of extremely high resolution.

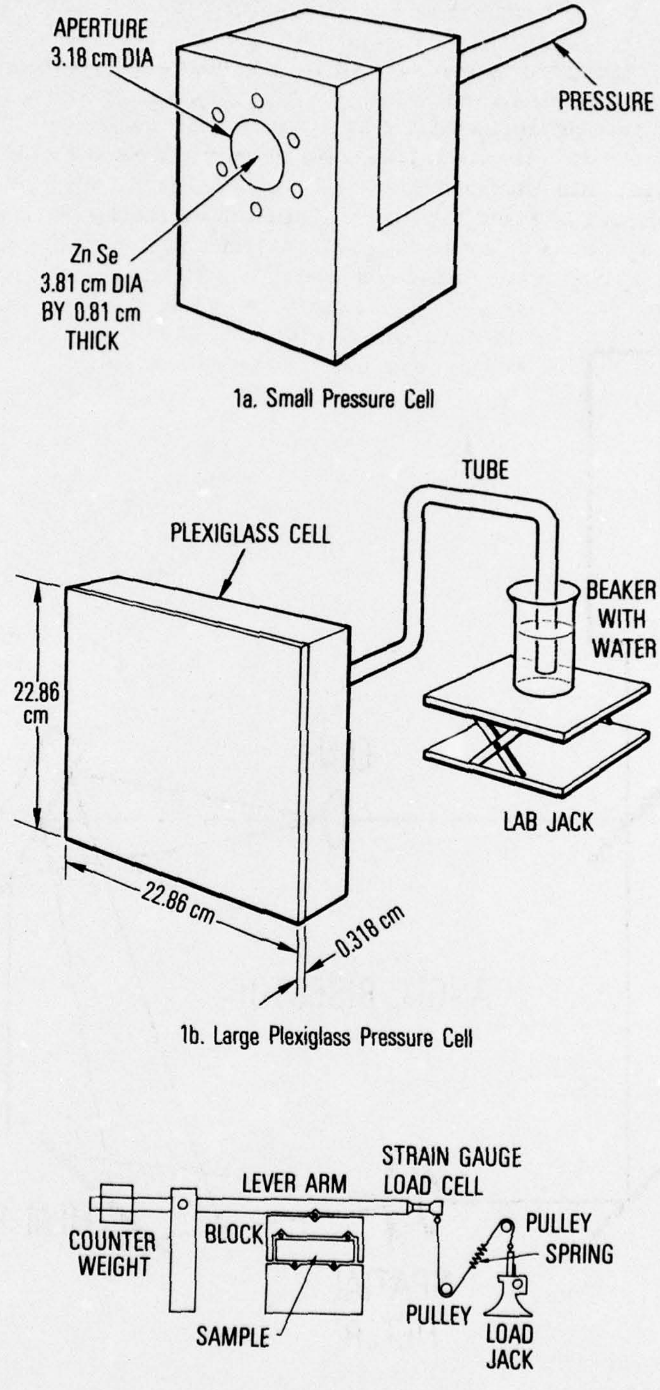


Figure 1. Test Fixtures

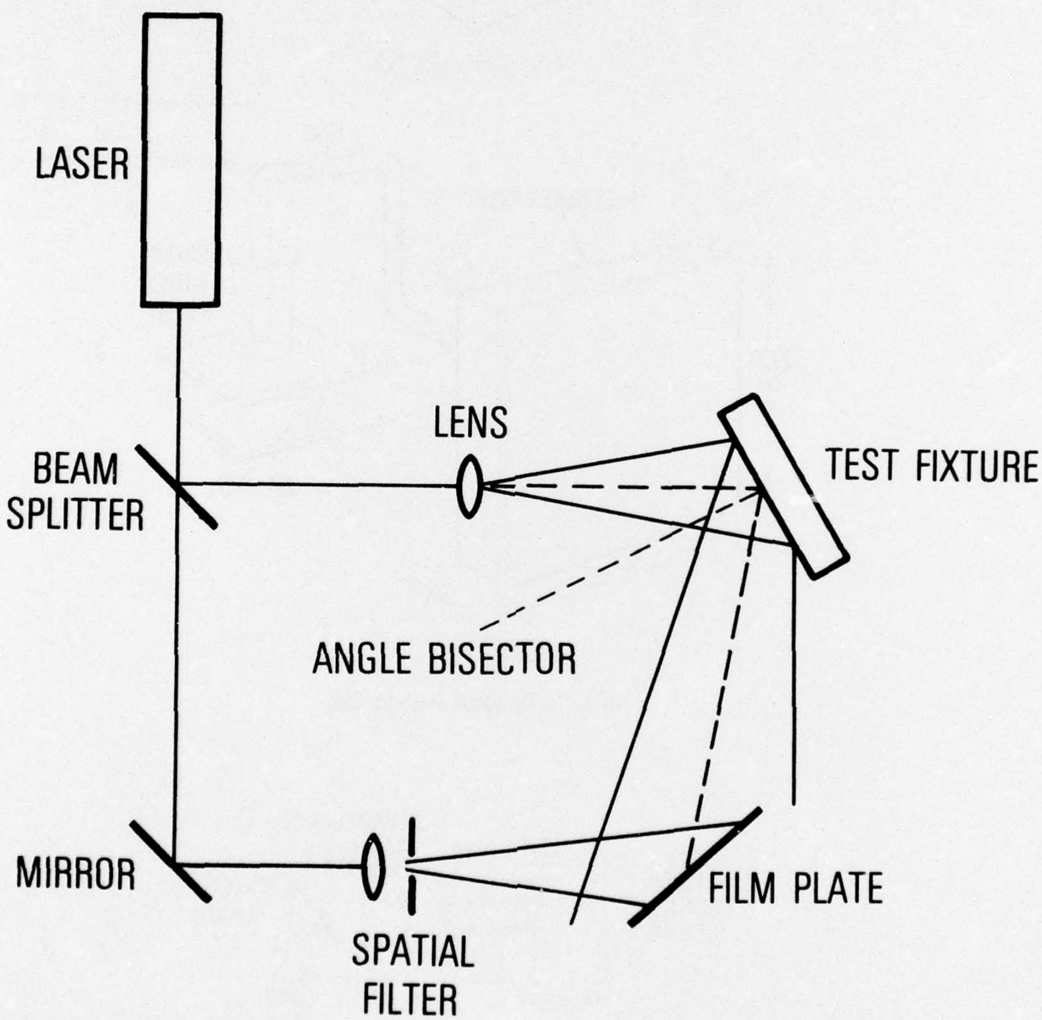


Figure 2. Experimental Holographic Arrangement

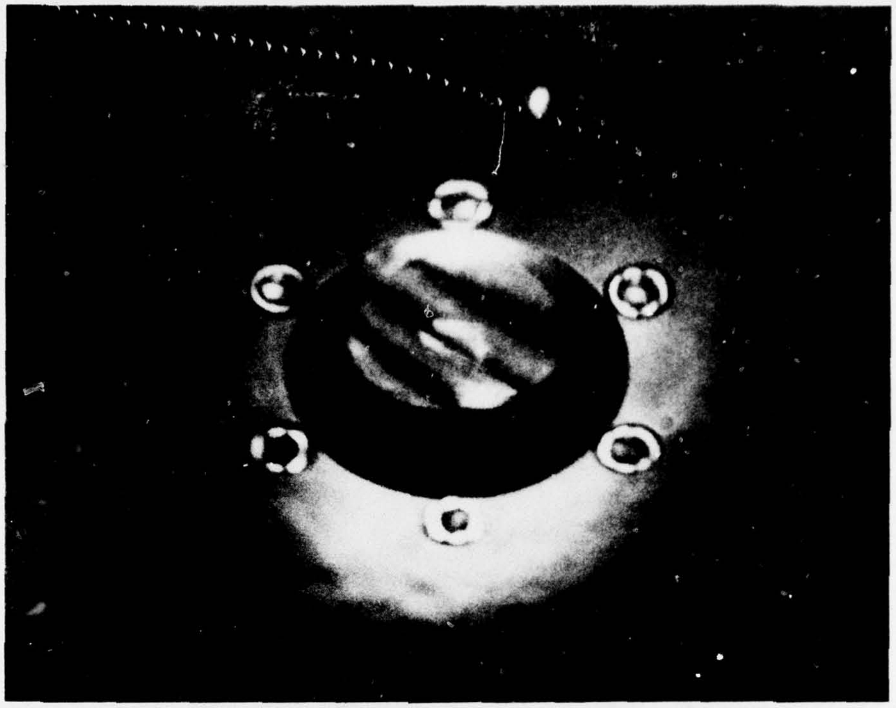


Figure 3. Typical Holographic Interferogram Obtained from a Small Pressure Cell

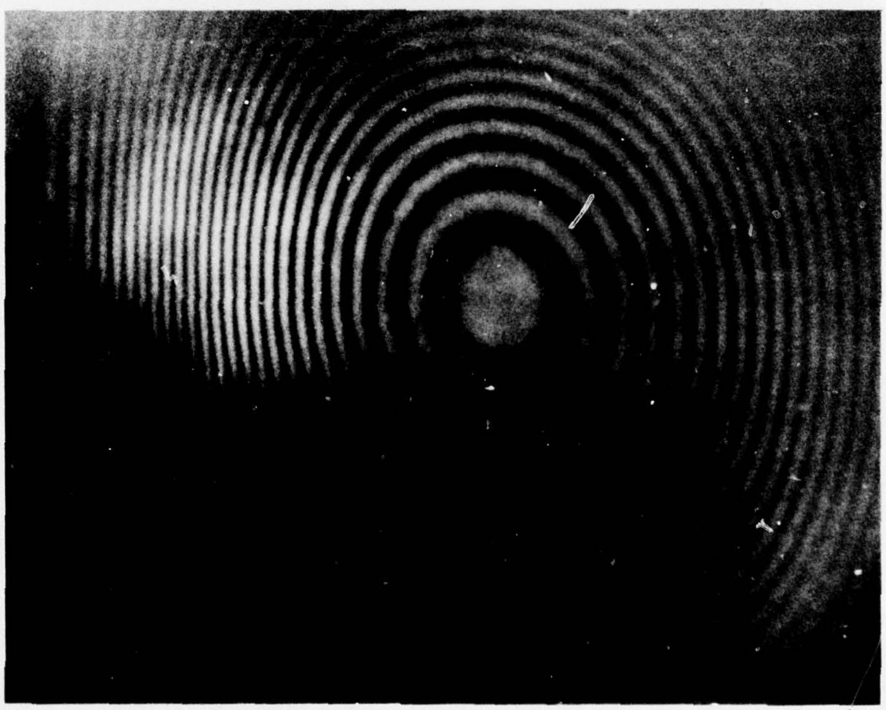
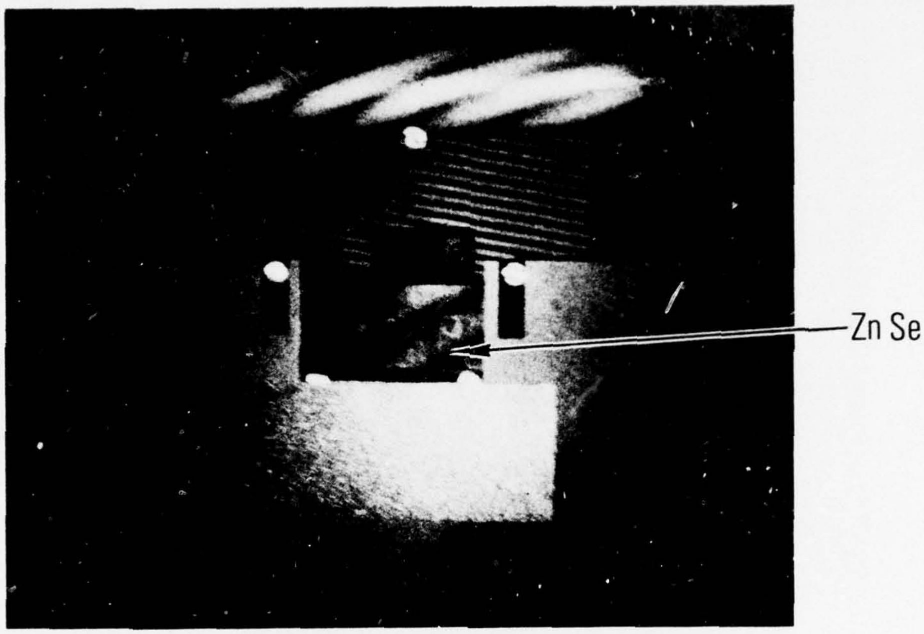
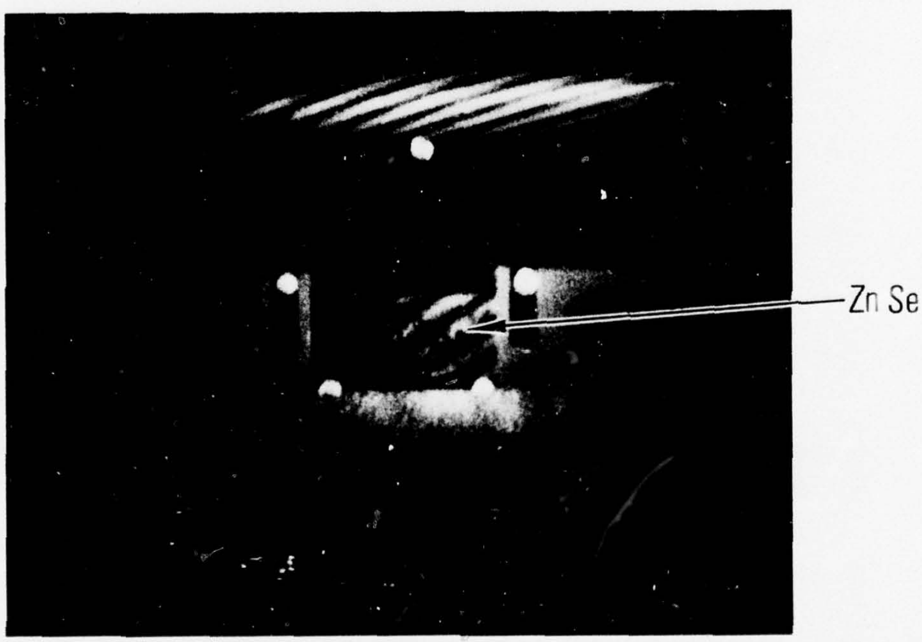


Figure 4. Typical Holographic Interferogram Obtained from the Central Region of a Plexiglass Cell (pressure = 5.15×10^{-3} psi)



5a. DIFFERENTIAL LOAD - 2 lb



5b. DIFFERENTIAL LOAD - 3 lb

Figure 5. Typical Interferograms Obtained from the Four-Point Loading Apparatus

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